

Health Effects of Indoor Fungal Bioaerosol Exposure

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Occupational and environmental health professionals are confronted with issues concerning the health effects of indoor fungal bioaerosol exposure. This article reviews current data on the health effects of indoor mold exposure and provides practical suggestions for occupational and environmental health practitioners regarding how best to manage these exposures based on published human studies. We conducted MEDLINE searches and reviewed all English language studies on indoor mold exposure (visible survey or objective sampling) and human health effects published from 1966 to November 2002. The main findings of the studies are analyzed in conjunction with plausible association of health effects and fungal exposure. Five case control studies, 17 cross-sectional surveys, and 7 case reports met the selection criteria. Current evidence suggests that excessive moisture promotes mold growth and is associated with an increased prevalence of symptoms due to irritation, allergy, and infection. However, specific human toxicity due to inhaled fungal toxins has not been scientifically established. Methods for measuring indoor bioaerosol exposure and health assessment are not well standardized, making interpretation of existing data difficult. Additional studies are needed to document human exposure-disease and dose-response relationships.

Keywords Bioaerosol, Indoor Air Quality, Mold, Allergy, Irritation, Mycotoxins, Mycotoxicosis

Indoor air quality (IAQ) concerns are important public health issues. Several national and international institutions have addressed the issue of health problems due to poor IAQ.⁽¹⁻⁴⁾ Occupational and environmental health professionals are increasingly being asked to investigate and manage incidents associated with indoor pollutants, particularly fungal exposure. For the purpose of operational consistency, "indoor" is referred to any enclosed space⁽³⁾ that people may occupy for occupational, avocational,

and recreational activities. This article reviews and summarizes current studies linking human health effects to indoor mold exposure. Possible mechanisms linking fungal exposure with human illness are discussed. Recommendations are provided for practicing occupational and environmental health professionals regarding how best to manage occupants and residents who either are exposed to mold or have concerns over mold exposure in indoor non-agricultural settings based on published human studies.

METHODS

We conducted MEDLINE searches using "and/or" with the keywords bioaerosol(s), mold, fungus, mycotoxin, dampness, indoor, indoor environment, health effects, respiratory, and sick building to find English language studies in the PubMed database published between 1966 and November 2002. The search yielded a total of 417 articles. Only human studies related to fungal/mold exposure were included in the selection process for further review. Bioaerosol sampling methodology, dust mite, insect, animal dander, bacteria, plant, and non-human studies were excluded. All original articles were obtained and reviewed for study purpose, methodology, exposure assessment, results, and conclusions.

RESULTS

Case-Control Studies

Of the 417 published papers retrieved from the searches, 5 are case-control studies.^(5-7,9,10) Three articles studied the possible association of *Stachybotrys chartarum* exposure and the development of pulmonary hemorrhage in infants living in the Cleveland area. Preliminary data appeared to show a risk to infants living in water-damaged houses with *Stachybotrys* exposure. Environmental tobacco smoke was also a risk factor. However, after conducting further analysis, the U.S. Centers for Disease Control and Prevention (CDC) reported that the association between *S. chartarum* and pulmonary hemorrhage was not proven.⁽⁸⁾ A descriptive paper on the clinical profile of infants

with acute pulmonary hemorrhage in Cleveland suggested potential roles of *Stachybotrys* toxins, but additional evidence to support causation is needed.⁽⁶⁸⁾

One European case-control study assessed moisture and visible mold in the homes of 102 asthmatic patients. One hundred ninety-six subjects without asthma served as controls. The study showed an increased prevalence of moisture and mold problems in the homes of asthmatic patients compared with controls.⁽⁹⁾ A study of 259 children with asthma or respiratory symptoms found an increase in dust mite and mold sensitization and a greater prevalence of mold and water problems in the home, compared to 257 children who had no respiratory symptoms.⁽¹⁰⁾

Cross-Sectional Studies

Seventeen cross-sectional studies were identified.^(11-26,67) Twenty-three office buildings without any known air quality problems situated at different sites around the island of Mauritius were studied for possible biological contamination and self-reported symptoms of sick building syndrome. No analysis of symptoms was provided in relationship to microbial sampling results. The authors noted that naturally ventilated buildings had significantly higher fungal concentrations (*Aspergillus*, *Penicillium*, and *Cladosporium*). They concluded that there is an association between onset of symptoms of sick building syndrome and microbial contaminations in the offices.⁽⁶⁷⁾

A survey of 488 building occupants was conducted for self-reported symptoms based on questionnaire. There was an increase in the rates of symptoms associated with visible fungal growth, airborne mold, and moisture. No new cases of allergic chest disease were identified after remediation for mold and moisture.⁽¹¹⁾ A study of 59 asthmatic patients from 46 households found some evidence of increased severity, particularly the frequency of emergency room visits, in those exposed to elevated indoor mold and bacteria.⁽¹²⁾ However, the sample size was small, and most associations were not statistically significant.

A sample of 403 Canadian children was evaluated for a relationship between reported mold growth and symptoms.⁽¹³⁾ There was a 12-50 percent increase in symptom prevalence (irritation, chest illness, cough/wheeze) associated with reported mold growth at home, but only a slightly increased prevalence of asthma. A study of 1129 school children found that the presence of molds or dampness in the house was related to hay fever, wheezing, and difficulty in breathing.⁽¹⁴⁾

An occupational assessment was conducted in response to toxic mold exposure. Site evaluation and air and surface samplings were performed in addition to selected medical testing of the building occupants.⁽¹⁵⁾ The authors concluded that presumed mycotoxin exposure was the possible or likely cause of asthma and interstitial lung disease (ILD). However, radiographic findings did not indicate ILD, and serum IgE or IgG antibody did not correlate with the presence of disease.

Another occupational investigation was conducted in response to health complaints among employees of a water-

damaged office building.⁽¹⁶⁾ Air and surface sampling of mold demonstrated evidence of fungal contamination. Occupants had a high prevalence of multiple symptoms, which became less prevalent after relocation from the building. After conducting site evaluation and bioaerosol sampling in day care centers, an association between "sick building syndrome" and exposure to dampness and *Aspergillus*, not *Penicillium* or *Cladosporium*, was suggested.⁽¹⁷⁾

An association between home dampness and respiratory symptoms of cough, wheeze, bronchitis, and asthma was found in a survey of 4164 school children.⁽¹⁸⁾ A health and immunology study was conducted in 53 office workers following exposure to toxigenic fungi in a water-damaged office. Subjective respiratory and other symptoms were associated with mold exposure.⁽¹⁹⁾ No case definition was provided, and no specific diagnosis was made in any of the workers evaluated. Immunologic tests performed were non-specific and inconclusive.

Parents of 470 children completed a questionnaire concerning damp stains and mold growth at home.⁽²⁰⁾ Children living in homes with those problems had an increased prevalence of asthma-like symptoms (chronic cough, shortness of breath, wheeze, and acute attacks of shortness of breath with wheeze.) However, most of the associations were not statistically significant. There was also an association between parental smoking and impaired pulmonary function in the male children. Questionnaires completed by 14,799 adults were used to identify home dampness, mold, and respiratory symptoms.⁽²¹⁾ There was an association between self-reported home dampness and mold and the presence of respiratory symptoms. Using the same database, a study of 13,495 children found that domestic exposure to dampness and mold was associated with a higher prevalence of respiratory problems.⁽²²⁾

In a study of 1000 children, a questionnaire survey was used to assess home dampness and visible mold as well as health symptoms. Air sampling and home visits were conducted in 88 homes. There was an increased prevalence of wheezing among children whose homes were reported to be moldy.⁽²³⁾ Air sampling results showed mold levels varied widely between houses, and that spore burden differed little between moldy and non-moldy homes. Parents and guardians of 4625 children completed questionnaires regarding home dampness, visible mold, and respiratory illnesses of the children.⁽²⁴⁾ In addition, the children also underwent spirometric testing. The study concluded that home dampness and mold were associated with self-reported respiratory symptoms and illnesses. However, there was only a minimal association between home dampness and mold exposure and spirometry results.

A study of 579 British households found that damp and moldy living conditions had an adverse effect on health, particularly in children.⁽²⁵⁾ Another questionnaire-based study was conducted on 519 occupants of 185 homes.⁽²⁶⁾ Home dampness was assessed, and viable mold spore measurements were performed in the living rooms of 36 homes. Respiratory symptoms were obtained by self-administered questionnaire. The authors found

that damp homes had higher average spore counts, and the occupants had a greater prevalence of respiratory symptoms.

Many of these studies used either questionnaire or symptom survey tools to obtain information on mold. Most provided no specific diagnosis or case definition. A few studies utilized surface and/or air sampling for mold. There were no standardized methods for collection and quantification of the sampling data. Often, these studies evaluated multiple possible associations, increasing the likelihood that at least some statistically positive results would occur on a random basis. Nevertheless, many concluded that there was an association between respiratory symptoms and putative indoor fungal exposures. Despite significant limitations, these studies suggest a trend toward increasing respiratory symptoms among those who occupied houses and buildings containing excessive moisture. An association between indoor mold and respiratory type symptoms is also suggested.

Case Reports

Currently, there are seven case reports associating indoor bioaerosols and mold with adverse health effects. There are two reports of ill-defined hypersensitive symptoms,^(27,32) two asthma case reports,^(29,33) and three reports of infants with pulmonary hemorrhage/hemosiderosis.⁽²⁸⁻³¹⁾ Four recent reports⁽²⁸⁻³¹⁾ indicate that the patients recovered completely after treatment or removal from further mold exposure. Tables I, II, and III summarize the published human studies and reports associating indoor mold exposure and adverse health effects.

DISCUSSION

Building-related complaints include diverse symptoms reported by occupants as the result of chemical, physical, and

biological exposures in the indoor environment. The most common are mucous membrane discomfort, headache, and fatigue. The term "sick building syndrome"⁽³⁴⁾ has been used when these symptoms occur in buildings, but no specific diagnosis can be established in the occupants. In contrast to sick building syndrome, the term "building-related illness" is appropriate when a medical condition or disease is identified in one or more affected individuals of that indoor environment and can plausibly be linked to exposures there. The disease is typically diagnosed by clinical manifestations and can be verified by laboratory studies. With proper therapeutic modalities and avoidance of the harmful exposure, the medical condition usually resolves.

Except for specific chemical or toxic gas exposures such as carbon monoxide, building related illnesses are usually associated with exposure to bioaerosols.^(35,36) Bioaerosols⁽³⁷⁾ are airborne particles that are living, or originated from living organisms. They include microorganisms, fragments, toxins, and particulate waste products from a variety of sources (e.g., viruses; bacteria; fungi; plants; protozoa; and animals such as arthropods, birds, and mammals). Bioaerosol hazards due to fungi are encountered in the indoor environment, agriculture, waste management, biotechnology industry, and healthcare. Bioaerosols can cause four types of human illness: allergy, infection, irritation, and toxicity.

Allergy and Hypersensitivity Diseases

Allergy and hypersensitivity diseases result from exposure to allergens that stimulate specific immunological responses. Detailed descriptions of allergic diseases are available in excellent textbooks.⁽³⁸⁾ Briefly, allergic rhinitis and asthma are associated with IgE-mediated response, while hypersensitivity pneumonitis

TABLE I
Summary of published case-control studies related to human health effects

Reference	Setting	Exposure assessment	Findings	Comments
CDC, Montana, Etzel ⁽⁵⁻⁷⁾	10 infants with acute pulmonary hemorrhage/hemosiderosis	Air and surface sampling for mold	OR: smoking household 7.9, water-damaged house 16.9, presence of <i>S. atra</i> 1.6	Association of mold growth in water-damaged homes and acute pulmonary hemorrhage/hemosiderosis
Williamson ⁽⁹⁾	102 asthmatics and 196 control subjects	Dampness survey of moisture and visible mold	OR: 1.9 current and 2.1 previous dampness. $r = 0.3$ for dampness and 0.23 for mold growth	Association of dampness and mold with asthma based on severity score and spirometry
Verhoeff ⁽¹⁰⁾	259 children with asthma or chronic cough symptoms and 257 controls	Signs of home dampness or mold by questionnaire and home visit	OR: 1.98 for reported dampness, 2.07 for reported mold	Association of damp house/mold and asthma or chronic cough

OR: Odds ratio.

TABLE II
Summary of published cross-sectional studies related to human health effects

Reference	Setting	Exposure assessment	Findings	Comments
Bholah ⁽⁶⁷⁾	23 office buildings without IAQ problems	Air sampling for bacteria, dust mites, and mold	Naturally ventilated buildings had higher fungi	Self-reported symptoms without specific diseases identified
Jarvis ⁽¹¹⁾	488 building occupants, 261 occupants of building with no known problems	Visual, air, and surface sampling	Allergic respiratory symptoms were associated with moisture and mold	Self-reported disease prevalence. No data on specific diseases
Ross ⁽¹²⁾	57 asthmatic adults	Air sampling for mold and dust sampling for mite antigen	Association of ER visits with total and Gram(-) bacteria and total mold spores	Increase in asthma severity indicators. No control subjects
Dales ⁽¹³⁾	403 elementary school children	History of mold growth, air sampling of bacterial endotoxin and mite antigen	12-50% increase in respiratory symptoms associated with mold growth	Mold was not sampled. No specific diagnosis was made
Jedrychowski ⁽¹⁴⁾	1129 school children	Outdoor air pollutant sampling and history of indoor dampness/mold	Presence of mold or dampness is associated with hay fever, wheezing, and difficulty breathing	Symptoms survey. No objective measure of mold problems
Hodgson ⁽¹⁵⁾	14 adults	Site evaluation, air and surface sampling for mold	Possible/likely building-related asthma, and symptoms of interstitial lung disease (ILD)	Presumed mycotoxin-induced effects. Case definition unclear. No radiographic evidence of ILD
Sudakin ⁽¹⁶⁾	37 adults	Site evaluation, air and surface sampling for mold and bacteria	High prevalence of multiple symptoms, neurobehavioral and upper respiratory complaints	Evidence of fungal (<i>Penicillium</i> and <i>Aspergillus</i>) and bacterial growth. Symptoms became less prevalent after relocation
Li ⁽¹⁷⁾	264 day care workers	Site evaluation, air and surface sampling for mold, bacteria, and dust mite	High prevalence of "sick-building syndrome" with exposure to dampness and <i>Aspergillus</i>	Symptom survey only; No specific diagnosis was made
Yang ⁽¹⁸⁾	4164 school children	Questionnaire survey of home dampness, visible mold, or flooding	Association of cough, wheezing, bronchitis, and asthma with dampness	Survey of health and exposure by self-reported questionnaires

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TABLE II
Summary of published cross-sectional studies related to human health effects (*Continued*)

Reference	Setting	Exposure assessment	Findings	Comments
Johanning ⁽¹⁹⁾	53 office workers	Air and surface/bulk sampling for mold and mycotoxin	Subjective respiratory and other symptoms associated with mold exposure	No sampling of the control environment. No specific diagnosis was made
Cuijper ⁽²⁰⁾	470 school children	Questionnaire survey of indoor environmental factors	Damp stains and mold growth are associated with chronic cough	Statistically significant association of asthma-like symptoms with passive smoking, but not mold growth
Dales ⁽²¹⁾	14,799 adults	Questionnaire survey of home dampness and mold	Dampness and mold were associated with respiratory symptoms	Self-reported symptoms and visible mold
Dales ⁽²²⁾	13,495 children	Same methodology and data base as above	Respiratory symptoms were more prevalent in homes with molds/dampness	Self-reported symptoms and visible mold by parents/guardians
Strachan ⁽²³⁾	1000 children	Questionnaire survey of symptoms, dampness and visible mold, followed with air sampling	Association of excess wheeze and moldy/damp homes	Sterile mycelia were higher in homes of wheezy children. Air sampling showed mold levels varied widely between houses
Brunekreff ⁽²⁴⁾	4625 children	Questionnaire survey of symptoms, dampness and visible mold	Increase in respiratory symptoms and dampness/mold	Self-reported symptoms and dampness/visible mold
Platt ⁽²⁵⁾	579 households	Assessment of dampness/mold and structured health interview	Association of respiratory symptoms with damp and moldy homes	Greater prevalence of symptoms among children
Waegemaekers ⁽²⁶⁾	519 adults and children	Questionnaire and air sampling for viable mold	Damp homes had higher rate of respiratory symptoms	Higher mold spore counts in damp homes

OR: Odds ratio; r: correlation coefficient; ER: Emergency room; IAQ: indoor air quality.

(HP) is associated with IgG and T cell responses. Allergic rhinitis and sinusitis can be diagnosed by the patient history, physical examination, presence of eosinophils in nasal smears, skin prick tests, and radioallergosorbent tests (RAST) demonstrating specific IgE antibody.

Asthma due to fungal allergens is characterized by complaints of chest tightness, wheezing, coughing, and shortness of breath,⁽²⁹⁾ typically occurring within one hour of exposure. The diagnosis is based upon the symptoms, physical exami-

nation, pulmonary function tests demonstrating reversible bronchospasm, or a positive methacholine challenge test. Bronchopulmonary aspergillosis (BPA) is an inflammatory disease caused by an immunological response to *Aspergillus fumigatus* and other *Aspergillus* species growing in the bronchi of patients with asthma.

HP is often more difficult to diagnose. In the acute form, symptoms include fever, cough, and chest tightness. The chest radiographs may show non-specific infiltrates or fibrosis.

TABLE III
Summary of published case reports related to human health effects

Reference	Setting	Exposure assessment	Findings	Comments
Trout ⁽²⁷⁾	Worker with hypersensitive (?) respiratory illness	Air and surface sampling	Identification of <i>Penicillium</i> , <i>Aspergillus</i> , and <i>Stachybotrys</i> spp.	Unclear medical diagnosis. Serology was not useful in identifying exposure
Novotny ⁽²⁸⁾	Infant with pulmonary hemorrhage	Air and surface sampling for mold	Isolation of <i>Penicillium</i> and <i>Trichoderma</i> from surface	Patient remained clinically healthy after discharge
Fung ⁽²⁹⁾	Asthmatic adult	Air and surface sampling for mold	(+) In vitro/in vivo test for <i>Alternaria</i>	Patient recovered with treatment and after fungal source was remediated
Elidemir ⁽³⁰⁾	Infant with pulmonary hemorrhage	Surface sampling for mold	<i>S. atra</i> , <i>Aspergillus</i> , and <i>Penicillium</i> were recovered	<i>S. atra</i> was recovered from BAL. Patient recovered completely
Flappan ⁽³¹⁾	Infant with pulmonary hemorrhage	Air and surface sampling for mold	<i>Stachybotrys</i> spores found in air sampling	Mycotoxin was found in mold-contaminated area
Croft ⁽³²⁾	4 family members and a maid	Fungal spores by impinger sampling. Ceiling and dust samples for mold	"Flu" symptoms. <i>S. atra</i> extracts found in ceiling and duct dust were toxic to animals	No objective evidence of specific disease detected. No further complaints after house was cleaned
Kozac ⁽³³⁾	7 children with asthma and/or allergy	Viable, non-viable spores, direct tape and bulk sample for mold	Clinical evidence of allergy and asthma. 1 child had positive skin prick for <i>S. atra</i>	Possible allergy to various fungi including <i>Stachybotrys</i>

Patients with chronic HP report insidious onset of cough, dyspnea, and fatigue. The diagnosis is based on patient history, physical findings, abnormal chest radiographs and CT scans, pulmonary function tests showing a restrictive pattern and reduced diffusion capacity, presence of antibody to the antigen, and presence of numerous lymphocytes on bronchoalveolar lavage. Lung biopsy may be needed to confirm the diagnosis.⁽⁵⁹⁾

Mycosis

Infection refers to the entry and multiplication of a biological agent in a host's body. Systemic fungal infections such as histoplasmosis, coccidioidomycosis, and cryptococcosis can occur when people are exposed to contaminated bird droppings or construction dusts. These environmental fungi *Coccidioides* (soil), *Cryptococcus* (bird dropping) and *Histoplasma* (bat dropping) may infect normal people. These are outdoor fungi and, theoretically, may be brought indoors. However, they have not been reported as health hazards in indoor environments.

Opportunistic mycoses are primarily restricted to severely immunocompromised subjects. Deep-tissue invasion of fungi

can occur to severely immunocompromised patients with lymphoproliferative disorders such as leukemia, cancer patients receiving chemotherapy, and those who receive immunosuppressive treatment for bone marrow or organ transplantation.⁽⁶⁴⁻⁶⁶⁾ Detailed description of mycoses can be found in standard textbooks.⁽³⁹⁾ Studies reviewed do not directly link indoor mold exposure and mycosis. It appears that human dose-response data are rarely available for fungal bioaerosols.

Irritation

Irritation due to bioaerosol exposure may result in conjunctivitis, rhinitis, and asthma. Exacerbation and aggravation of pre-existing allergic rhinitis or asthma may be triggered by exposure to irritants. Mold can produce a variety of organic chemicals including alcohols, aldehydes, geosmin, and sulfur-containing chemicals producing typical musty and pungent odors.⁽⁴⁰⁻⁴²⁾ Glucans are glucose polymers found in most fungal cell walls. Exposure to airborne (1 → 3) beta-D-glucan has been associated with airway inflammation.⁽⁴³⁾ Mechanical effects of spores and mycelia debris may also cause mucous membrane irritation.

Irritation may be associated with trigeminal nerve stimulation.⁽⁴⁴⁾ Pungent odors may provoke responses such as breath holding, and reports of tingling and burning sensation of the skin. Under unusual circumstances, volatile organic chemicals emitted from mold and building materials may reach levels sufficient to produce central nervous symptoms such as headache, inability to concentrate, or dizziness.^(44,60,61)

Mycotoxicosis

Toxicity due to fungal exposure is caused by secondary metabolites produced by molds. Molds produce antibiotics and mycotoxins in order to provide a competitive advantage over other mold species and bacteria. Mycotoxins are by-products of mold metabolism. They are typically cytotoxic, disrupting cell membranes and interfering with protein and RNA/DNA synthesis. Not all molds produce mycotoxins. Toxicogenic molds vary in their mycotoxin production depending upon the substrate, and environmental factors (e.g., temperature, relative humidity, light, presence of oxygen and carbon dioxide) as well as seasonal and life-cycle stages.⁽⁶²⁾ It is important to point out that the presence of a toxigenic mold in an indoor environment does not prove that the occupants have been exposed to mycotoxins.⁽⁵¹⁾

Historically, ergotism is one of the earliest conditions linked to mycotoxins, and is caused by ingestion of rye contaminated with the fungus *Claviceps purpurea*.⁽⁴⁵⁾ Toxicity due to aflatoxins produced by *Aspergillus flavus* was first documented in 1960 and is known as the turkey X disease. Diseases associated with aflatoxin by ingestion route include the acute syndrome of fatty liver, hepatic necrosis, and encephalopathy similar to Reye's syndrome. Chronic exposure to food contaminated with aflatoxins is associated with hepatocellular carcinoma.⁽⁴⁶⁾ *Aspergillus parasiticus* also produces aflatoxins. *Aspergillus versicolor* does not produce aflatoxin, but produces the aflatoxin precursor sterigmatocystin.

Mycotoxin exposure is not a new issue, especially in agricultural setting and food contamination. A review of human studies on *Stachybotrys* mycotoxin exposure indicates that with sufficient dose, mycotoxins may produce immunosuppressive and inflammatory insults to gastrointestinal and pulmonary systems.⁽²⁷⁾ Recently, much media attention is given to *S. chartarum* (*atra*). It is a mold species that is typically slimy and not easily aerosolized. This mold has a very low nitrogen requirement and can grow on paper, ceiling tiles, carpets, and insulation materials made of cellulose. There is controversy concerning a possible link between *stachybotrys* mycotoxin exposure and acute pulmonary hemorrhage and death in infants.^(47,48) After conducting further review of the original data by internal and external panels, it was apparent that the association was based on flawed methodology and overestimation of the odds ratios. As a result, the Centers for Disease Control and Prevention recently issued a report indicating that the association had not been proven.⁽⁹⁾

Stachybotrys mycotoxins such as stachybotrins have HIV protease inhibitory and endothelin receptor antagonistic

effects.^(49,50) Documenting toxic effects from any mycotoxin should include (a) presence of airborne spores containing toxin, (b) levels of toxin exposure sufficient to cause disease, and (c) observed health effects related to toxin exposure rather than other components of the spores. A critical review of literature on the health effects of mycotoxins in indoor air concludes that mycotoxin levels expected in most mold-contaminated indoor environments are not likely to result in measurable health effects.⁽⁵¹⁾

The presence of a specific fungal antibody in serum implies previous exposure to that mold. It is not an indication of disease. Recently, *S. chartarum* antigen was found to cross-react with antibodies of *Aspergillus fumigatus* and *Alternaria alternata*, which are common outdoor fungi.⁽⁵²⁾ Thus a positive antibody test may not mean that the patient has been exposed to *S. chartarum*. The level of antibody present in serum following exposure and sensitization to *S. chartarum* is not predictable.⁽⁵²⁾ Therefore, *S. chartarum* IgG antibodies cannot be used to establish the date or source of last exposure.

Although cancer has been associated with ingestion of mycotoxins, particularly aflatoxins, current evidence indicates that cancer due to inhaling mycotoxin requires chronic exposure in heavily contaminated industrial environments.⁽⁵³⁾

Assessing and Controlling Fungal Exposures

There is a lack of discussion in the studies reviewed on how to appropriately manage individuals exposed to indoor mold and also a lack of specific mold level that may prevent mold-related illnesses. Exposure limits, such as threshold limit values (TLVs), are intended to prevent harmful effects caused by airborne contaminants. Typically, they are based on epidemiological studies of people with a wide range of exposures. The basic philosophy of these limits is that they will prevent disease despite a lifetime of exposure. For example, the current permissible exposure limit (PEL) for asbestos is 0.1 fibers/cc, which is several hundred times lower than the levels of industrial exposure that occurred in the past.

In contrast to the well-established health effects of asbestos and other mineral dusts at various levels, there is a lack of epidemiological and clinical data that establish exposure-disease and dose-response relationships for fungal bioaerosols. The diversity of biological agents, and their various effects on individuals, makes it difficult to establish safe limits. Multiple agents are usually involved.

Currently, the methods of collecting and measuring fungi and their metabolic by-products are not well standardized. There is a paucity of data on levels in the environment, and the health effects in exposed populations are not well understood. Therefore, no exposure limits can be set at this time.^(37,63) Additional review of published documents on patient management revealed only guidelines.

Guidelines for assessing and controlling fungal exposures are based more on a consensus of researchers and practitioners

rather than objective scientific data.^(37,54-58) Despite a lack of exposure standards for mold exposure, it is important for occupational and environmental practitioners to investigate the exposure as scientifically indicated.⁽³⁷⁾ Additionally, the building occupants or residents of a home should be evaluated by health-care provider for assessing possible building-related illness. It is important that collaborated efforts between the industrial hygiene and medical providers using combination of clinical tools for accurate diagnosis with the best possible data concerning the environmental exposure in order to establish a link. Environmental exposure assessment is necessary when medical diagnosis is consistent with a mold-associated illness. On the other hand, caution is warranted in advising building occupants, since sweeping statements such as "Move out of your house" or "Get out of the building" have significant psychosocial and economic consequences. Problems such as leaking roofs or cracked pipes should be obvious and relatively easy to correct.

In most cases, areas of mold contamination can usually be remediated with fairly straightforward measures. However, moisture problems (and consequential mold growth) in some building systems may be more difficult to resolve. In these cases where condensation, capillary movement of water, moisture in building envelopes, etc., are suspected, engineering, architectural, and other professionals should be consulted. When water intrusion and moisture problems are identified and remediated, mold-related issues should eventually resolve.

CONCLUSIONS

Health effects caused by fungal bioaerosol exposure include allergy, infection, irritation, and toxicity. While the first three categories have well-established mechanisms, there is a lack of dose-response data, and a highly variable degree of individual susceptibility. Specific human toxicity due to inhaled mycotoxins is not well understood, and the likelihood that sufficient mycotoxins are airborne despite visible indoor mold remains unproven and controversial. Excessive moisture is a risk factor for mold proliferation. Thus, it is prudent to identify the source of moisture, and then repair and fix water intrusion problems before starting an expensive and usually low-yield environmental investigation. However, if a moisture problem has resulted in extensive fungal growth, an environmental investigation with emphasis on physical inspection is recommended. More complicated problems may require services from other professionals including engineers and architects. Proper building design and construction, with periodic maintenance to avoid water intrusion, are important measures in preventing health effects due to fungal contamination.

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